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Microcontroller based Insulation Resistance Tester with Data Logging Facility

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ABSTRACT

The Insulation Resistance tester (IR tester) is a maintenance device for electrical systems. It measures the insulation level of a insulators. It is designed as a portable device as well as it has the capability of holding the data and upload it to a computer at a later time. The backbone of this device is the stable high voltage power supply. It is powered by domestic power line. Displaying, voltage measuring, memory handling functions are handled by a PIC 16F877 microcontroller. It has a 4-digit Seven Segment Display panel and a 64k memory module. The user must hold the probes on the testing material for a period of one minute continuously. During that period the device will activate a timer that counts 59 seconds and the result will be displayed in the 60th second. The instrument covered insulation range of 1 MΩ to 1 GΩ with the accuracy of 0.1%. The measured results are stored in memory for future use. The memory can hold up to 68 samples and data can be uploaded to a computer by the software designed for this device. By analyzing the data the dielectric absorption ratio (DAR) and the polarization index (PI) can be calculated.

1. INTRODUCTION

By definition a dielectric material is an insulator. The ideal dielectric would be vacuum or infinite impedance. In simple sense a material that does not allow a electric current to flow through it at any potential difference is an ideal insulator. However, real world dielectrics do not have infinite impedance and therefore are not perfect. Hence working with these non-perfect insulators, it is critical to measure its limitations as a safety precaution. Also insulation value of an insulator is not static against environmental conditions, over time. Insulation starts to age as soon as it's made. As it ages, its insulating performance deteriorates. This deterioration can result in dangerous conditions in power reliability and personnel safety. Insulation is subject to many effects which can cause it to fail; such as, mechanical damage, vibration, excessive heat, cold, dirt, oil, corrosive vapors, moisture from processes, or just the humidity on a muggy day. As pin holes or cracks develop, moisture and foreign matter penetrate the surfaces of the insulation, providing a low resistance path for leakage current. As such, it's important to identify this deterioration quickly so that corrective steps can be taken. One of the simplest tests and its required test instrument are Insulation Resistance testing (IR testing) and the megohmmeter or more commonly called megger. Insulation resistance, the characteristic of an insulating material that being subject to voltage, indicates a resistance such that the value of the leakage current which flows through it stays within acceptable limits. The leakage Current is the steady state current flowing through an insulating material that is subjected to high voltage.

1.1. Theory behind insulation resistance tester

Insulation resistance tester uses basically Ohm's law. But in theory Ohm's law doesn't apply to insulators, it applies to conductors only. And it's time independent. That means irrespective of the time interval that voltage is applied across a conductor the same current will flow through it. The main feature of an insulator against a conductor is that the current through an insulator is time dependent. More precisely the current through an insulator decreases with time. When a voltage is applied to the insulator a small current is observed through the insulator. This current has three components such as capacitance charging current, absorption current, and leakage or conduction current as shown in the Figure 1a [1]. The leakage or conduction current is the main current concerned in measuring the resistance of the insulator. This leakage current will increase as the insulation ages. It also will worsen when the insulation is wet or contaminated. Since these three components vary with time the insulation measurement is also time-dependent. The experimental graph in Figure 1b [1] shows how each current component change with time. The "conduction or leakage current" starts at zero, and quickly increases to a final value depending on the characteristics of the insulator. This is the way that good insulation behaves. The total current flowing in the circuit is equal to the sum of the components mentioned above. The total current flow, when a DC voltage is applied, starts at a relatively high value and then drops, settling at a value just slightly above the leakage current. In bad or deteriorated insulation, the total current will drop slowly, or may even increase. Insulation Resistance is calculated by dividing applied voltage by the measured current at the measuring instance.

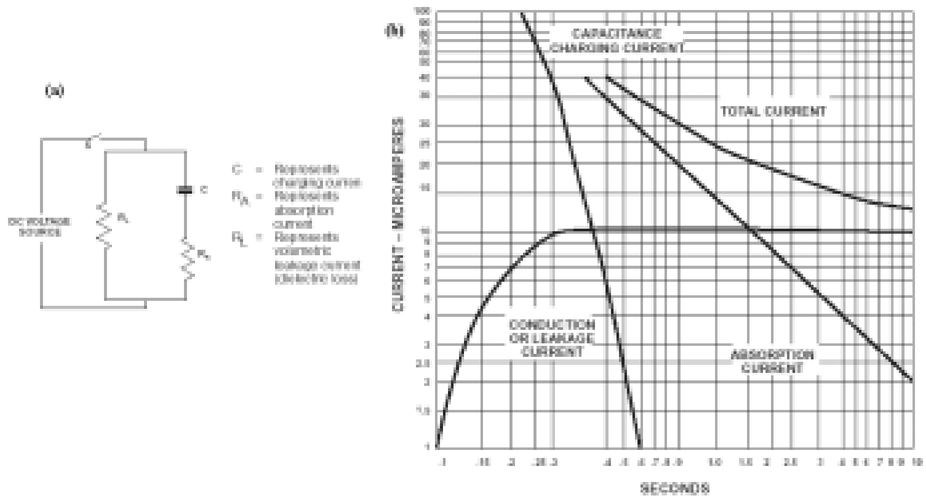

Figure 1: (a) Equivalent circuit of an insulator. (b) Graphical representation of leakage current

1.2. Tests conducted by the insulation resistance tester

Insulation resistance (IR) is inversely proportional to the leakage current. But the leakage current deteriorates with time. Hence the insulation resistance also increases with time. It induces the problem of assigning a value of insulation resistance of a sample. Dielectric absorption ratio test recognizes the fact that "good" insulation will show a gradually increasing IR after the test voltage is applied. After the connections are made, the test voltage is applied, and the IR is read at two different times: usually either 30 and 60 sec, or 60 sec and 10 min. The later reading is divided by the earlier reading, the result being the *dielectric absorption ratio(DAR)* [1]. The 10 min./60 sec. ratio is called the *polarization index (PI)* [1]. Various sources have tables of acceptable values of dielectric absorption ratios and polarization index.

1.3. About this work

The main objective of this work is to design a low cost insulation resistance tester. It is particularly intended for testing insulation of electrical appliance, fittings and accessories. More accurately it can measure insulation levels of electrical systems domestically, commercially, and in scientific laboratories. It can be used for experimental purposes. For example it can be used to carry out experiments regarding insulation level of various kinds of material.

The constructed instrument is having main features such as it shows the insulation resistance of the test object after one minute of connecting the probes, during the measurement a timer is displayed in the panel that allows the user to track the time needs for measurement, and the measured results are stored in memory for future use. Custom made software is offered with the instrument to download the measured data to computer. This software is equipped with a database that store measured data according to the date and time they were downloaded to computer.

2. DESIGN AND METHODOLOGY

The constructed IR tester has seven major sub-circuit modules named *High Voltage Source*, *Current sensor*, *Display unit*, *Timer circuit*, *Memory module*, *Serial interface module*, and *Measurement probes* integrated with the *Main control unit*.

2.1.High voltage source

Out of the seven major parts of the IR tester, the most essential part is the high voltage source. High voltage source is essential because a measurable current will not pass through the insulator otherwise. This out put voltage of the high voltage source should be stable and must have the capability of handling up to 10 mA or otherwise the measurement will be inaccurate. The high voltage source consists of a step-up transformer (230V:1000V), high voltage diode bridge, smoothing capacitor network, and regulating mechanism.

The regulating mechanism was the tricky part. There were no zener diodes available in the market that can handle up to this voltage level. Hence eight zener diodes were used in series to account for the zener voltage. It arouses another problem. When the zeners are used in series the total error in zener voltage is increased and this is unavoidable situation. But the zener rating is improved by applying a shunt transistor regulating circuit. Figure 2 shows the circuit diagram for the voltage source with the regulation circuit.

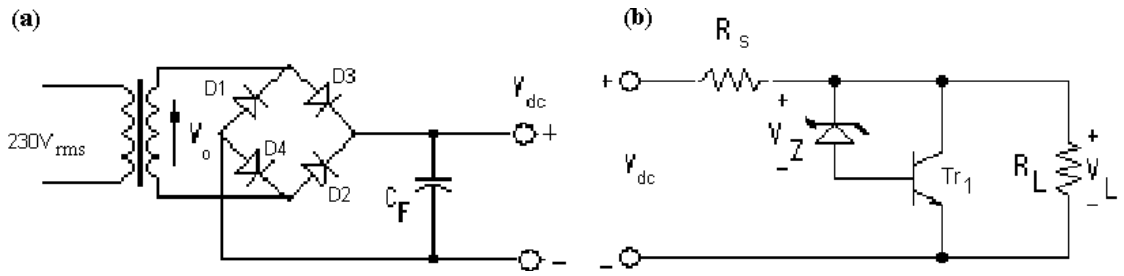

Figure 2: (a) Power supply circuit. (b) Shunt regulator

The main component in the voltage source is the transformer. There are no transformers available in the market that gives 1 kV as the output. Hence there is no other option than to wind one from a local transformer manufacturer. For the rectifying bridge four IN4007 diodes (D_{1-4}) are used as shown in Figure 2(a). They have 1 kV breakdown voltage and well suited for the requirement. As the smoothing capacitor, a high voltage capacitor with enough capacitance is needed. By considering the availability of the market two capacitors of 270 μF/450V and two capacitors of 4700 μF/50V are used in series. This combination gave relatively high capacitance and collective breakdown voltage of 1 kV. The capacitor network is shown as C_F in Figure 2(a). For zener regulation two 110 V zeners (BZX85C110) [2] and six 130 V zeners (BZX85C130) [3] are used. For the transistor shunt voltage regulator as shown in Figure 2(b), a high voltage Darlington transistor (Tr_1) 2SD1555 [4] is used.

2.2. Current Sensor

This is the part where the actual measuring is done. The only measurement of the instrument is the leakage current going through the insulation material. Hence the adopted method to measure the current should be able to measure very low currents. Practically the current is in the order of microamps or even nanoamps. So the method used in this tester is first to convert the current to a voltage and measure the voltage by the internal ADC of the PIC-Microcontroller [5]. The conversion of current to voltage method is simply applying appropriate resistor series to the current path. Then the voltage is output to the microcontroller via an op-amp in its follower mode. The necessary bias voltage to the op-amp is given from the secondary power supply. Here two resistors are used via a switch to measure micro-ampere region and the nano-ampere region. Figure 3 shows the circuit diagram for the current sensor used for this work.

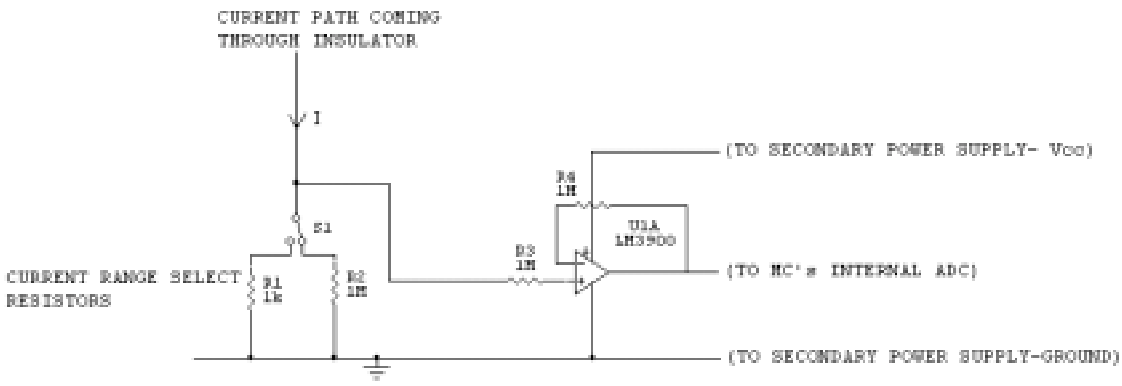

Figure 3: Current sensor circuit

The current sensor consists of two resistors, a switch and a voltage follower. The two resistors are used to select the current ranges. This is because the ADC set to read from 1 mV to 1.024V. The ADC resolution was change to the range mentioned above because that would give more accuracy. As the voltage follower LM3900 [6] op-amp is used because it has very low bias current. It is very accurate in the voltage-following mode. S1 switch shown in Figure 3 is not a manual switch. This was done because the current is sensed during a time interval. During that time when the current comes to the range boarder it is not practical to select resistor values manually. Hence the dynamic selection is done by sending a pulse from the PORTB of the microcontroller. For switching, transistor switches are used as shown in Figure 4(a).

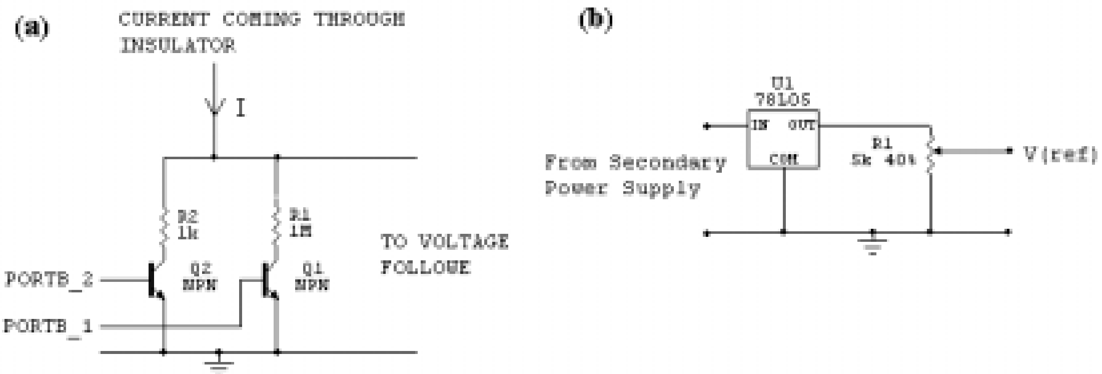

Figure 4: (a) Dynamic switch for the current sensor. (b) Voltage reference for ADC

The main part of the current sensor is to measure the output voltage from the voltage follower and was done by using the internal ADC of the microcontroller. To make the resolution 1 mV per step the ADC has to be given a reference voltage. This is given by a regulator and a potential divider as shown in Figure 4(b). It is possible just use a potential divider and use the regulator of the microcontroller. But this may cause the reference voltage to vary because the microcontroller circuit draws a lot of current from the regulator so that a separate regulator was used.

2.3.Main Control unit

The control unit was implemented by PIC16F877 [5] microcontroller. The microcontroller is used in many respects in this project. The main functions of the microcontroller are:

- Measuring the voltage from the current sensor.
- Timer component
- Display the IR reading in the display panel
- Store data in the non-volatile parallel memory chip
- Serial communication with the PC

The block diagram which includes all above operations mentioned above is shown in the Figure 5.

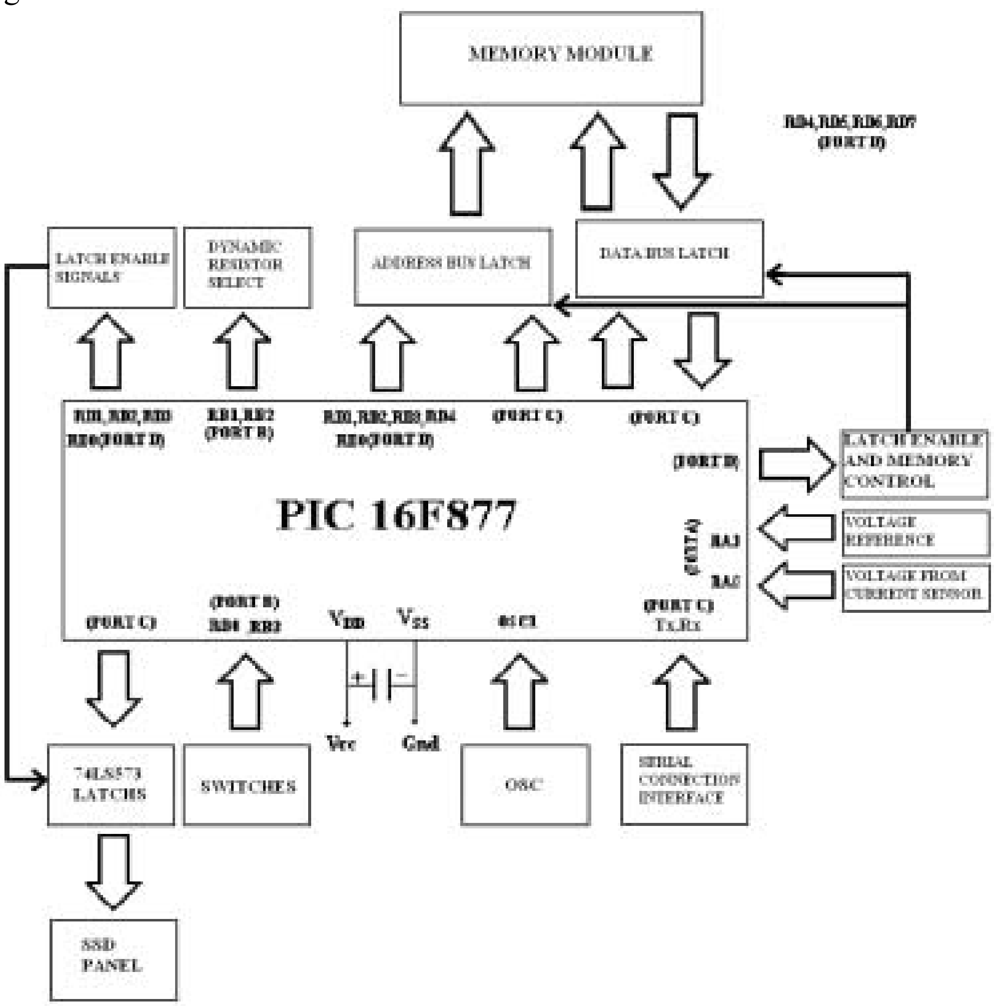

Figure 5: Block diagram of the Main Control Unit

The most critical operations done by the microcontroller is the measuring of voltage and the timer component which is critical to the IR measurement. For the timing component the microcontroller's internal delay functions are used in the program. When the voltage is applied to the insulator, ADC will measure the total current in one second intervals. The measured current values are stored in the non-volatile memory chip. Then at the 60^{th} second the current (i.e. leakage current) is stored in the memory and the insulation resistance is calculated from the calibration curve of the instrument. Then the relevant insulation resistance value is displayed in the display unit.

The memory can contain over 65 samples of 60 second current measurements. These 60 current measurements are uploaded to the computer via a serial channel in the microcontroller board. The results are properly interpreted by custom made software. This software stores the results in an *Excel spreadsheet*. The user can analyze the data in the spreadsheet and get the characteristic curve corresponding to the measured samples of insulation. A 64k non volatile ram chip DS1225AD [7] is used for the memory purposes. The serial connection here is implemented by a MAX232 [8] driver. The serial connection serves two purposes here. First it is the means of programming the microcontroller. Secondly it is used to transfer saved measurements in the memory chip. IR tester usually has high voltage outputs including this instrument. Hence it is necessary to use special probes for few reasons like the safety of the user, to ensure the accuracy of the measurements, and to safeguard the instrument. To achieve these goals the probe has to withstand more than the output voltage of the device. A special cable with 2000V rating was used as the probes. The instrument was calibrated using 12 standard resistors in the range of 1 MΩ to 2000 MΩ.

3. DISCUSSION AND CONCLUSION

The main goal of this project is to build a low cost insulation resistance tester. Comparing the price of IR tester available in the market, objective is well achieved by the product made under this project. Apart from the cost this project offer a product with some interesting features that only have in IR testers above Rs. 100,000. The instrument covered insulation range of 1 MΩ to 1 GΩ with the accuracy of 0.1% providing the correct current range select switch has been selected. The features offered are:

- Indicate the insulation resistance of the test object after one minute of connecting the probes.
- During the measuring time; a timer is displayed in the panel that allows the user to track the time needs for measurement.
- The measured results are stored in memory for future use.
- The memory can hold up to 68 samples of one minute measurements.
- A software package to operate the instrument.
- By analyzing the data the *dielectric absorption ratio* (DAR) and the *polarization index* (PI) can be calculated.

This software is equipped with a database that store measured results according to the date and time they were downloaded to computer. The results can be viewed using the software developed for this work. If the user prefers to use results with other software, provisions is made in this software to export the data to a spread sheet. This enables the user to analyze data as he wishes.

The manufacturing cost of the device could be less than Rs 5,000/- which is several times cheaper than the commercial insulation testers already in the market. The instrument was made as a portable package. It is useful to test onsite.

The memory capability gives added advantage to the user. This might save time taken to writing down the test values on paper. The instrument is designed to be flexible by the onboard serial connection so one can program to the microcontroller and use the instrument for some specific use. One port of the microcontroller is kept unused. The main intension of this is by a simple alteration to the circuit the memory can be expanded up to 2 Megabytes. By changing the program slightly this can be used as a resistance tester, continuity tester, or volt meter.

Before using one minute setup time is recommended so that the capacitors could be fully charged. User must never touch the two lead ends when doing the measurements. When taking the measurement, the probes must be applied a period of one minute to the test object.

Just after applying the voltage to the test object *START* button must be pushed for the measurement to begin. After every session the capacitors must be discharged by switching on the discharging switches in the write sequence as stated in the instrument face. This is crucial for the safety of the user. Only one discharging switch must be at a time. User must make sure that when plugging on the instrument all the discharging must be off.

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